PB85-169613

Field Confirmation of a Laboratory-Derived Hazard Assessment of the Acute Toxicity of Fenthion to Pink Shrimp, 'Penaeus duorarum'

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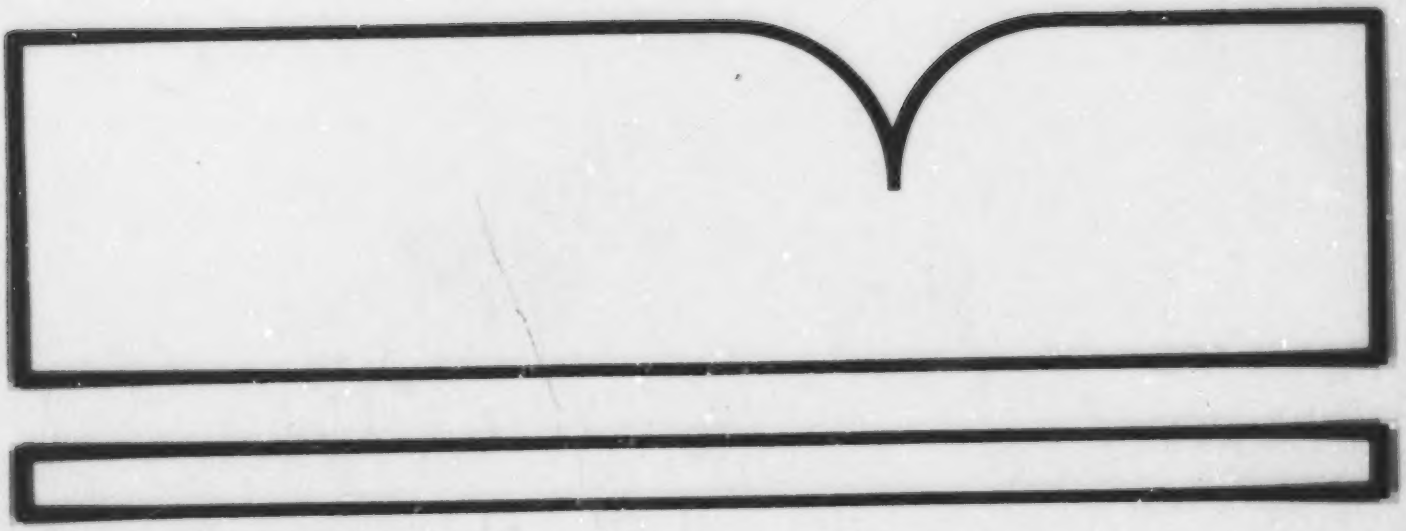
Feb 85



U.S. Department of Commerce
National Technical Information Service
NTIS

PB85-169613

EPA/600/D-85/033
February 1985

FIELD CONFIRMATION OF A LABORATORY-DERIVED HAZARD ASSESSMENT OF THE ACUTE TOXICITY OF FENTHION TO PINK SHRIMP, *Penaeus duorarum*

by

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1. REPORT NO. EPA/600/D-85/033	2.	3. RECIPIENT'S ACCESSION NO. PB85 169613/AS
4. TITLE AND SUBTITLE FIELD CONFIRMATION OF A LABORATORY-DERIVED HAZARD ASSESSMENT OF THE ACUTE TOXICITY OF FENTHION TO PINK SHRIMP, PENAEUS DUORARUM		5. REPORT DATE February 1985 6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) P.W. Borthwick, J.R. Clark, R.M. Montgomery, J. M. Patrick, Jr., & F.M. Lores		8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS		10. PROGRAM ELEMENT NO. 11. CONTRACT/GRANT NO.
12. SPONSORING AGENCY NAME AND ADDRESS U.S. Environmental Protection Agency Environmental Research Laboratory Office of Research & Development Gulf Breeze, FL 32561		13. TYPE OF REPORT AND PERIOD COVERED 14. SPONSORING AGENCY CODE EPA/600/04

15. SUPPLEMENTARY NOTES

16. ABSTRACT

Field studies were conducted to determine if laboratory protocols accurately predict shrimp mortality under field conditions. Fenthion, a mosquitocide, was applied to coastal marshes in several truck-mounted ultra-low volume (ULV) adulticide operations, and by direct application at the larvicide rate. Pink shrimp (Penaeus duorarum) were deployed in floating cages and observed for mortality. Water samples characterized the exposure regime and fate of fenthion at the field sites. The acute flow-through 96-h LC50 of 0.11 µg/ℓ was used as a conservative estimate of the expected toxicity in field exposures. An exposure profile based on measured field concentrations was used for laboratory pulse-exposures: fenthion was metered for 2 h to specified maximum concentrations, then flushed with seawater to cause a 6 to 8 h exposure, yielding a no-observed-effect concentration (NOEC) of 0.84 µg/ℓ. Four ULV sprays produced water concentrations <NOEC and no fenthion-induced shrimp mortality. However, the direct application's water concentrations ranged from 15 to 20 µg/ℓ (>NOEC) and caused extensive mortality (90 to 100%). Field observations confirmed our hypothesis that if peak fenthion concentrations were lower than the laboratory NOEC, then no mortality would occur, whereas if maximum concentrations exceeded the NOEC, mortality would occur. These laboratory toxicity tests can predict the range of lethal and non-lethal acute field exposures to fenthion for pink shrimp when exposure regimes are similar.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS OPEN ENDED TERMS	c. COSATI Field/Group

18. DISTRIBUTION STATEMENT Release to public	19. SECURITY CLASS (This Report) unclassified	21. NO. OF PAGES 26
	20. SECURITY CLASS (This Page) unclassified	22. PRICE

EPA Form 2220-1 (Rev. 4-77) PREVIOUS EDITION IS OBSOLETE

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Field Confirmation of a Laboratory-Derived Hazard Assessment of the Acute Toxicity of Fenthion to Pink Shrimp, Penaeus duorarum

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ABSTRACT: Field studies were conducted to determine if laboratory protocols accurately predict shrimp mortality under field conditions. To evaluate the applicability of laboratory data, fenthion, a mosquitocide, was applied to coastal black rush (Juncus roemerianus) marshes in several truck-mounted ultra-low volume (ULV) adulticide operations and by direct application at the larvicide rate. Caged pink shrimp (Penaeus duorarum) were deployed in floating compartmented cages and observed frequently over a 24-h period for mortality. Water samples collected for gas chromatographic quantitation characterized the exposure concentration regime and fate of fenthion at the field sites. Field data were compared to laboratory acute toxicity data from ASTM standard practice flow-through tests. The acute flow-through 96-h LC50 of 0.11 µg/ℓ was used as a conservative estimate of the expected toxicity in field exposures. An exposure profile based on measured field concentrations was used for laboratory pulse-exposure tests: fenthion was metered for 2 h to specified maximum concentrations, then flushed with seawater to cause a 6 to 8 h exposure, yielding a no-observed-effect concentration (NOEC) of 0.84 µg/ℓ. In field tests, four ULV operations produced initial water concentrations <NOEC and no fenthion-induced shrimp mortality. However, the direct application's initial water concentrations ranged from 15 to 20 µg/ℓ (>NOEC) and caused extensive mortality (90 to 100%) in the caged shrimp. Thus, field observations confirmed our hypothesis that if fenthion time-exposure concentrations were lower than the laboratory NOEC, then no mortality would occur in caged shrimp. Moreover, if initial concentrations in the field exceeded the laboratory NOEC, mortality would occur. These laboratory tests and field applications indicate that laboratory toxicity tests can predict the range of lethal and non-lethal acute field exposures to fenthion for pink shrimp when exposure regimes are similar.

KEY WORDS: acute toxicity, aquatic toxicology, crustacea, fenthion, field testing, pesticides, Penaeus, pink shrimp, pulse exposure

Introduction

Field studies of pesticides under actual use conditions are necessary to determine the accuracy and applicability of existing procedures for hazard assessment. Cairns et al. [1,2][3] provided rigorous reviews of sequential testing procedures for hazard assessment and the application of arbitrary safety factors. Sperling [3] defined a safety level as "a sharp concentration limit of any noxious substance in food or water above which several significant effects can be found and below which, however, no effect would be observed at all." Further, if environmental concentrations are kept significantly below the "safety level" (by applying a "safety factor") one can assume that no adverse effect will occur. By comparing results of field studies with predictions based on laboratory data and hazard assessment protocols, prediction of environmental effects from a generalized hazard assessment scheme can be evaluated.

Several recent reviews and field studies indicate that massive fish kills or destruction of shellfish populations occur primarily under conditions of gross product misuse, accidental spills, or in chronically polluted areas USEPA [4], Mulla and Mian [5], Mulla et al. [6], and USEPA [7].

The objectives of our field study were to obtain data on environmental concentrations of fenthion following actual use application, to determine the response of caged test pink shrimp in the field, and to compare these results with data from routine laboratory toxicity tests.

Fenthion (O,O-Dimethyl O-[3-methyl-4-(methylthio)phenyl] phosphorothioate; Baytex®, (Mobay Chemical Corp., Agricultural Chemicals Division) is an organophosphate insecticide used to control adult saltmarsh mosquitoes in marshgrass and mangrove habitats. Laboratory tests have shown this pesticide to be acutely toxic to marine crustaceans at concentrations that may be encountered in normal use patterns (if hazard assessment predictions are accurate). We evaluated fenthion

in the field at rates used for control of mosquitoes in aquatic habitats because these rates are used in hazard assessment procedures. Acute, lethal responses were measured as a first step in direct laboratory-field comparisons.

Field application of fenthion was made by the West Florida Arthropod Research Laboratory (WFARL) from truck-mounted, ultra low volume (ULV) equipment. The pesticide was applied under normal use conditions in a manner consistent with label restrictions and recommendations to two black rush, Juncus roemerianus, marshes (Sites 1 and 2) at Eglin Air Force Base near Ft. Walton Beach, Florida. Monitoring equipment and caged adult mosquitoes were deployed to assess meteorological conditions and efficacy of four ULV sprays on May 5 and 10, June 13, and July 11, 1983.

In addition to the ULV adulticide sprays, fenthion was applied on August 10, 1983, at the larvicide rate directly into the water of the same two saltmarsh lagoons (Sites 1 and 2). This application yielded water concentrations high enough to test the applicablity of laboratory toxicity data.

Procedures

Laboratory Toxicity Tests

We determined the toxicity of fenthion to estuarine organisms in acute lethality tests with five species: Mysidopsis bahia (mysid), Palaemonetes pugio (grass shrimp), Penaeus duorarum (pink shrimp), Cyprinodon variegatus (sheepshead minnow), and Menidia beryllina (inland silverside). Each of these species was collected from local waters, except P. duorarum which was purchased from a local bait dealer when needed. These tests were conducted to provide laboratory data for selection of the most appropriate species for testing in cages in the field. LC_{50} values were used to determine the most

sensitive organisms and the range of concentrations at which they were affected. All acute toxicity tests were conducted according to the ASTM "Standard Practice for Conducting Acute Toxicity Tests with Fishes, Macroinvertebrates, and Amphibians (E729-80)". Acute static toxicity tests were conducted with all five species to determine 24- and 48-h LC_{50}'s. Continuous-exposoure acute flow-through tests were conducted only with mysids and pink shrimp (the most sensitive species) to determine 24-, 48-, 72-, and 96-h LC_{50}'s.

Natural seawater from Santa Rosa Sound was filtered through sand and a 20-µm polypropylene filter. All tests were conducted at 25 $\pm$ 1°C and salinity was maintained at 20 $\pm$ 1 °/oo by freshwater dilution. However, there was no adjustment to increase the salinity if it fell below 20 °/oo, as happened with one pink shrimp static test conducted at 14 °/oo. Dissolved oxygen (DO) and pH were measured at 24-h intervals and the photoperiod was 14L/10D for all tests. The static tests with pink shrimp were monitored hourly to remove dead animals and to measure DO. LC_{50} values were calculated by the probit and binomial methods [8].

Cyprinodon variegatus brood stocks were allowed to spawn in aquaria [9] and broods were hatched and reared in the laboratory. Fourteen-day-old fry were tested in 2-ℓ culture dishes and were not fed during the 48-h tests. Menidia beryllina brood stock was spawned and reared in the laboratory [10]. Fourteen-day-old fry were exposed to fenthion in 3.8-ℓ glass battery jars and the fry were fed Artemia nauplii (32-48 h post-hydration) twice daily during the 48-h tests. Palaemonetes pugio juveniles were acclimated to test conditions for 1 week. Test aquaria were 3.8-ℓ glass battery jars covered with glass tops to prevent escape of test animals. Mysidopsis bahia juveniles (24-32 h old) were collected from laboratory cultures. They were exposed to fenthion in 2 ℓ culture dishes for static tests, or in 13 ℓ aquaria during flow-through

tests. Mysids were fed Artemia nauplii (24-32 h post-hydration) once daily for the duration of all tests. Penaeus duorarum, approximately 5 g live weight, were acclimated to laboratory conditions for 4 days prior to testing. Static tests were conducted in glass tanks with a capacity of 70 to 80 ℓ and covered with acrylic plastic to prevent escape of test animals. Halfway through (24 h) the 48 h test with P. duorarum, DO had dropped to approximately 65% saturation. To prevent DO from decreasing further, airstones were placed in exposure aquaria approximately 10 cm below the water's surface. Flow-through tests with penaeids were conducted with 30 ℓ/h flow rates in 40-50ℓ test aquaria.

Test media were analyzed chemically for both mysid and penaeid flow-through exposures, and LC_{50} values were calculated using average measured fenthion concentrations.

Pulse Exposure Toxicity Tests

Laboratory pulse exposures were conducted with 20 P. duorarum (5g; 71 mm ave length) per 60-ℓ aquarium equipped with self-starting overflow siphons. Test shrimp were obtained from a local bait dealer and acclimated to test conditions in filtered seawater at 22°C and salinity from 23 to 26°/oo. Pulse exposures consisted of a 2-h period when seawater (30 ℓ/h) with added stock solutions of fenthion in triethylene glycol (TEG) were introduced into the aquaria to give maximum concentrations of 60, 6.4, 5.9, 3.6, 2.1, 1.8, 1.8, 1.7 and 0.84 µg/ℓ. The toxicant flow was then stopped and the aquaria allowed to flush with uncontaminated seawater at 15, 23 or 30 ℓ/h (clearance rates). Water samples were taken hourly for the first 4 h of exposure to characterize the rapid rise and fall of test concentrations. Exposure concentrations for the remaining time intervals were calculated from theoretical exchange rates [11]. Shrimp mortality was monitored for 96 h.

Deployment of Caged Pink Shrimp

Pink shrimp were selected for field exposure in cages because of their short-term acute sensitivity to fenthion. Each group of shrimp was identified taxonomically, measured, and when necessary, acclimated in the laboratory or field to the appropriate temperature and salinity regime for the exposure sites. Pink shrimp cages were of the same design as that used by Tagatz et al. [12] for holding grass shrimp, P. pugio. Each acrylic plastic (3mm thickness) cage consisted of a rectangular block (51 x 12 x 13 cm) of 10 adjacent compartments with a Styrofoam® lid (51 x 12 x 1.7 cm) which served as a float. The two opposite vertical sides of each cage were covered with Nitex® screen (1.8 mm mesh) to facilitate exposure to the surrounding medium.

Spray Conditions And Efficacy

The two study sites were sprayed on May 5 and 10, June 13, and July 11, 1983 (Sprays 1 through 4, respectively) with fenthion to control adult saltmarsh mosquitoes. Baytex® (93% liquid concentrate) was applied at dusk with a truck-mounted, Leco HD ultra low volume (ULV) aerosol generator (non-thermal) at a rate of 30 ml/min at a truck speed of 16 km/h (equivalent to 11 g/ha or 0.01 lb/ acre). Excellent mosquito control (>80% kill) and spray distribution over the study sites were obtained except for Site 2 on Spray 1 and Site 1 on Spray 3, when less than ideal wind speeds and directions prevailed.

In a fifth treatment on August 10, 1983 fenthion was applied directly to the saltmarsh lagoons at 56 g/ha (0.05 lb/acre), a rate consistent with the label rate for larvicidal activity. Since the larvicidal formulations of fenthion use a diesel fuel carrier that is toxic to marine life and may have complicated comparisons with previous ULV applications and laboratory toxicity data, we chose to apply the pesticide (Baytex®; 93% liquid concentrate) in

TEG carrier.

Fenthion was applied directly from the bow of a boat with a hand-held, pressurized sprayer and a stock solution of 9.9 g fenthion per liter of TEG. The solution was applied (5.7 ℓ/ha) between 0800 and 0900 h during an early flood tide to minimize transport from the lagoons into Santa Rosa Sound and to maximize mixing and dilution from the initial high concentrations as tidal volume in the embayment increased. No efficacy tests were conducted with mosquitoes for this application since the primary interest was to characterize responses of caged pink shrimp following a predicted "adverse-effect" application, not to control mosquito larvae.

Analytical Chemistry Methods

Water samples and pink shrimp were analyzed for fenthion using the method of Lores et al. [13]. The lower limit of detection was 0.010 µg/ℓ for water samples and 0.010 µg/g for shrimp tissues.

Results

Laboratory Acute Toxicity Tests

Results of acute static and flow-through tests for fenthion and five marine species considered for field evaluation tests are given in Table 1. The crustaceans were 200 to 5,600 times more sensitive than fishes (24h static test).

The fish showed an immediate stress response when exposed to fenthion. Inland silversides exhibited signs of distress (spiral swimming, jumping, and clumping of chromatophores) during the 3rd or 4th h of exposure. Sheepshead minnows showed similar effects by the 8th h of exposure. Fish deaths occurred between the 4th and 16th h, and mortality diminished gradually, with almost none occurring after 48 h of exposure.

Early (before 8 to 16 h of exposure) visible effects of stress noted in

crustaceans included color changes from pink to red and erratic swimming behavior in pink shrimp. Toxicity to penaeids in flow-through tests was similar to that in static tests. However, the mysids were somewhat more sensitive in flow-through tests compared to static exposures. Toxicity increased with time for both flow-through tests with both mysids and pink shrimp.

Table 2 summarizes results of pulse-exposures of pink shrimp. Mortality was monitored for 96 h, although all deaths occurred within the first 24 h following exposure. In four tests where maximum water concentrations reached 60, 6.4, 5.9 or 3.6 µg/ℓ, all shrimp were killed. Between 45 and 85 percent of the shrimp died between maximum concentrations of 1.7 and 2.1 µg/ℓ, and clearance rates of 15, 23 or 30 ℓ/h. No deaths were recorded in control aquaria or for the lowest pulse exposure in which the water concentration peaked at 0.84 µg/ℓ.

Fenthion Concentration In Water Following Field Application

Measured water concentrations decreased with time, after fenthion was applied to the surface due to vertical mixing, tidal dilution and flushing, and degradation. At Site 1, maximum concentrations following ULV Sprays 1 through 4 reached 0.28, 0.68, 0.47 and 1.1 µg/ℓ, respectively. After Sprays 1-3, fenthion concentrations were highest within the first h post-spray, decreasing to less than 0.03 µg/ℓ within 6 h, and none was detected after 18 h. Following Spray 4, no fenthion was detected in samples taken 0.5 h post-spray, diminishing any possible effect of the 1.1 µg/ℓ maximum water concentration. Warm ground temperature and strong southerly winds at the time of Spray 4 resulted in limited deposition of fenthion. At Site 2, fenthion was not detected in water 6 h post-spray, except following Spray 2 when 0.16, 0.04 and 0.04 µg/ℓ were recorded at 12, 18 and 24 h, respectively. Maximum water

concentrations at Site 2 following Sprays 1 through 4 were 0.06, 0.38, 0.48, and 0.21 µg/ℓ, respectively. A comprehensive account of fenthion concentrations in water samples is given by Moore et al. [14].

Following direct application of 56 g/ha (0.05 lb/acre) to the water, concentrations of fenthion in surface samples at Site 1 ranged from 15 to 42 µg/ℓ during the first 15 min after application. Detectable fenthion residues persisted for 48 h. Water samples contained residues of fenthion at the greatest sampling depths (1 meter) from 15 min to 12 h after spraying, when bottom sampling stopped. In surface samples taken at Site 2, fenthion ranged from a maximum of 45 µg/ℓ immediately following application to 0.016 µg/ℓ 48 h after the spray. The pattern of dilution and dispersion could be followed longer after direct application (than after ULV applications) because initial water concentrations were much higher. However, patterns of disappearence were similar.

Survival Of Caged Pink Shrimp

The response of caged pink shrimp to fenthion was related to method of application. The relationships among results of constant-exposure and pulse-exposure tests in the laboratory, and field exposures are summarized in Figure 1. Following single ULV applications of fenthion, maximum water concentrations exceeded the 96 h lethal concentrations for caged invertebrates predicted from laboratory data generated in constant-exposure tests. The four ULV sprays caused no deaths of caged pink shrimp in aquatic habitats at rates that killed mosquitoes placed aerially in cages just above adjacent juncus marsh. However, extensive exposure-related deaths of pink shrimp occurred after direct application of fenthion to the water at the larvicidal rate. At Site 1, after 6 h of exposure, 90% of the pink shrimp had died and no other deaths occurred during 48 h observation. At Site 2, mortality was 100% within

4 h of application. Control mortality was 8% after 48 h.

Discussion

Field Exposure Assessment

The EPA registration label warns that fenthion should not be used in areas where shrimp or crabs are important resources, although Special Local Need Registrations may be granted under Section 24(c), Federal Insecticide Fungicide and Rodenticide Act.

Our laboratory toxicity data (Table 1) illustrates the sensitivity of three crustaceans, particularly pink shrimp, to acute fenthion exposure.

In Table 2, the no-observed-effect concentration (NOEC) for pink shrimp in laboratory pulse exposures is 0.84 µg/ℓ (maximum fenthion concentration). However, by increasing the NOEC by a factor of 4.3, a maximum fenthion concentration of 3.6 µg/ℓ killed 100% of the test animals. Based on these laboratory results, we predicted that if maximum field concentrations following ULV mosquitocide were less than 0.84 µg/ℓ caged shrimp would survive. Further, peak concentrations between 0.84 and 3.6 µg/ℓ would cause partial kills and sublethal effects, and if fenthion concentrations exceed 3.6 µg/ℓ, then high partial kills to complete mortality would occur.

Additional acute toxicity data for fenthion and freshwater and estuarine crustaceans are presented in Table 3. The lowest freshwater 48-h EC50's were with instars of two cladocerans, 0.62 µg/ℓ for *Simocephalus serrulatus* and 0.80 µg/ℓ for *Daphnia pulex* [15]. Both values are comparable to our 48-h LC50 of 0.44 µg/ℓ for estuarine mysids. Earlier studies indicate that penaeid shrimp are extremely sensitive to fenthion: 48-h EC50's (based on mortality or loss of equilibrium) were 0.024 µg/ℓ for brown shrimp (*Penaeus aztecus*), and 0.032 µg/ℓ for pink shrimp*. In the present study, the 48-h LC50 for pink shrimp in flowing water is 0.22 µg/ℓ.

* Lowe, J.I., Environmental Protection Agency, Environmental Research Laboratory, Gulf Breeze, FL (personal communication)

In laboratory tests, Chang and Lange [16] obtained a 36-h EC50 of 22 µg/ℓ fenthion for red crayfish (Procambarus clarki). In California rice fields treated aerially with 0.2 lb/acre-ft (~ 68 µg/ℓ), 100% of these organisms held in submerged cages were killed at the beginning of the rice-growing season, but efficiacy (crayfish control) was considerably reduced later in the season when there was a thick stand of rice plants.

In fish hatchery ponds, Ray and Stevens [17] tested fenthion for control of crayfish, Procambarus simulans and Orconectes nais, and obtained a 75% kill by exposure to 22 µg/ℓ. In the same study, fingerling channel catfish (Ictalurus punctatus), striped bass (Morone saxatilis) and largemouth bass (Micropterus salmoides), all 5 to 10 cm in length, were unharmed after 96 h exposure to application rates as great as 0.7 lb/acre-ft (250 µg/ℓ).

In the present field study, ULV applications of 0.01 lb fenthion/acre to control adult saltmarsh mosquitoes produced water concentrations less than the 3.7 µg/ℓ predicted for an acre-ft of water, assuming that all of the pesticide entered the water. Within 4 to 6 h after application, water concentrations were reduced to 1 to 2% of predicted values, probably because of rapid mixing within the lagoon and tidal flushing. Lethal concentrations were not sustained for sufficient time to cause deaths and none of the caged pink shrimp exhibited acute responses attributable to fenthion exposure following ULV applications to control adult mosquitoes.

Direct application of fenthion to the water's surface at the larvicide rate produced initial pesticide concentrations (15 µg/ℓ) consistent with the assumption of 100% incorporation and mixing. As with ULV sprays, peak concentrations following direct application diminished rapidly. Nevertheless, all caged penaeid shrimp at one site were killed by direct application of fenthion, and 90% were killed at the other. This application should be viewed as a field

verification of nontarget effects of technical fenthion applied at the larvicidal rate to produce aqueous concentrations expected to affect marine biota, rather than assessment of a larvicide since a larvicidal formulation was not used.

General Conclusion

Whether sprayed directly or by ULV methods, fenthion toxicity to caged pink shrimp placed in the field can be predicted with data obtained from laboratory toxicity tests. The exposure-response analyses and direct observations reported here provide a means for evaluating the reliability of hazard assessment procedures now being used for pesticide registration. Predictions of deleterious environmental impact of a pesticide should consider that exposure concentrations following field applications may not always attain predicted "worst case" values and thereby lead to predictions of adverse effects that may not occur. Further, responses from laboratory toxicity tests in which concentrations remain constant throughout the test may not predict the responses of animals that experience pulse-exposures under natural conditions. Pulse-exposure laboratory toxicity tests that are designed to mimic field exposure regimes based on empirical data can better estimate the acute hazard to non-target aquatic organisms.

Acknowledgements

We thank the U.S. Air Force, the Eglin AFB Armament Division and especially Lt. Col. R. Hartman of the Environmental Protection Division, Eglin AFB, for allowing us to conduct our study at a secured site. B.W. Clements, C. Rathburn, J. Dukes and P. Hester of the West Florida Arthropod Research Laboratory conducted applications of fenthion and caged mosquito monitoring. Laboratory staff members V. Caston, S. Foss, M. Kasic, J. Knight, P. Moody, R. Stanley, and M. Stubbs provided invaluable scientific and technical assistance.

This paper is Contribution No. 494 from the Environmental Research Laboratory, Gulf Breeze, Florida.

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Table 1. Acute toxicity of fenthion to selected estuarine crustaceans and fishes.

Species	Age	Dosing[a]	LC50 (95% C.I), µg/L 24 h	48h	72h	96h
Mysid *Mysidopsis bahia*	1 d	S	0.77 (0.67 - 0.87)	0.44 (0.33 - 0.52)		
		FT	0.42 (0.26 - 0.81)	0.37 (0.22 - 0.77)	0.18 (0.15 - 0.22)	0.15 (0.12 - 0.19)
Grass shrimp *Palaemonetes pugio*	Juvenile	S	9.5 (7.5 - 12.0)	4.7 (3.5 - 5.7)		
Pink shrimp *Penaeus duorarum*	Juvenile	S	0.50[c,d] (0.18 - 0.65)	0.25[d] (0.21 - 0.30)		
		FT	0.40 (0.35 - 0.48)	0.22[c] (0.12 - 0.29)	0.15 (0.13 - 0.17)	0.11 (0.09 - 0.12)
Inland silverside *Menidia beryllina*	14 d	S	2,250 (2,000 - 2,520)	2,150 (1,920 - 2,410)		
Sheepshead minnow *Cyprinodon variegatus*	14 d	S	1,890[c] (1,690 - 2,250)	1,890[c] (1,690 - 2,250)		

[a] S = Static
FT = Flow-through
[b] LC50 values (95 percent confidence intervals) were computed using probit analysis or bionomial test and expressed as micrograms of fenthion per liter of seawater (25 ± 1°C; 20 ± 1°/oo)
[c] Binomial test
[d] Salinity = 14°/oo

Table 2. Data from flow-through laboratory toxicity tests with fenthion: Comparison of pink shrimp mortality in pulse-exposure and constant-exposure acute toxicity tests with fenthion

EXPOSURE REGIME	MAXIMUM CONCENTRATION (µg/ℓ)	MORTALITY (%)
INDIVIDUAL PULSE-EXPOSURES	(6 tests)	
12h	3.6[a]	100
"	2.1	70
"	1.8	60
"	1.8	85
"	1.7	45
"	0.84	NONE
CONSTANT-EXPOSURES		
8h	0.46	NONE
8h	0.88	50
24h	0.40[b]	50
48h	0.22[b]	50
72h	0.15[b]	50
96h	0.11[b]	50

[a]Additional 12h pulse exposures with maximum concentrations of 5.9, 6.4, and 60 µg/ℓ caused complete mortality by 12-h

[b]Calculated LC50 from pink shrimp flow-through test (Table 1)

Table 3. Acute toxicity data for aquatic crustaceans exposed to fenthion

Freshwater Species	Life stage or weight (g)	Temp. (°C)	Test[a] System	96-h LC50 95% CI (µg/ℓ)	Reference
Cladoceran, *Simocephalus serrulatus*	first instar	21	S	0.62[b] 0.44-0.87	15
Cladoceran, *Daphnia pulex*	first instar	15	S	0.80[b] 0.56-1.2	"
Cladoceran, *Daphnia pulex*	<24-hr old	21	S	3.6[c] 2.3-5.7	18
Ostracod, *Cypridopsis vidua*	mature	21	S	18[b]	15
Isopod, *Asellus brevicaudus*	mature	21	S	1,800 1,100-4,900	"
Amphipod, *Gammarus lacustris*	mature	21	S	8.4 5.0-12.0	"
Grass shrimp, *Palaemonetes kadiakensis*	mature	21	S	10[d] 7.1-14.0	"
Red crayfish, *Procambarus clarki*	15-25	22-26	S	22[e]	16
Crayfish, *Orconectes nais*	early instar	21	S	50[f] 35-90	15

Table 3. continued.

Estuarine Species	Life stage or weight (g)	Temp. (°C)	Test[a] System	96-h LC50 95% CI (µg/ℓ)	Reference
Blue crab, *Callinectes sapidus*	Juvenile	28	FT	3.6[g],2.3[h]	Footnote[i]
Brown shrimp *Penaeus aztecus*	Juvenile	30	FT	0.032[g], 0.024[h]	"
Pink shrimp *Penaeus duorarum*	Juvenile	30	FT	0.20[g], 0.032[h]	"

[a]S=static, FT=flow-through
[b]48-h EC50.
[c]48-h LC50.
[d]Hard water (272 mg/ℓ $CaCO_3$).
[e]36-h LC50
[f]Five-day LC50
[g]24-h EC50 based on mortality or loss of equilibrium
[h]48-h EC50 based on mortality or loss of equilibrium
[i]Lowe, J.I., Environmental Protection Agency, Gulf Breeze, FL, personal communication

Figure 1. Conceptual diagram illustrating the relationships among LC_{50} values from laboratory constant exposure toxicity tests (dotted lines) and pulse-exposure test results (open circles) with pink shrimp, and the fenthion concentration profile observed in the field (closed circles).